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(54) SYSTEM AND METHOD FOR ENERGY DISTRIBUTION

SYSTEM UND VERFAHREN ZUR ENERGIEVERTEILUNG

SYSTÈME ET PROCÉDÉ POUR LA DISTRIBUTION D'ÉNERGIE

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(73) Proprietors:
• **Robert Bosch GmbH**
70442 Stuttgart (DE)
• **Subbotin, Maksim, V.**
San Carlos, CA 94070 (US)
• **Roy, Binayak**
Mountain View, CA 94040 (US)
• **Krupadanam, Ashish, Samuel**
Cupertino, CA 95014 (US)
• **Ahmed, Jasim**
Mountain View, CA 94041 (US)

(72) Inventors:
• **SUBBOTIN, Maksim, V.**
San Carlos, CA 94070 (US)
• **ROY, Binayak**
Mountain View, CA 94040 (US)
• **KRUPADANAM, Ashish, S.**
Cupertino, CA 95014 (US)
• **AHMED, Jasim**
Mountain View, CA 94041 (US)

(74) Representative: **Bee, Joachim**
Robert Bosch GmbH, C/IPE
P.O. Box 30 02 20
70442 Stuttgart (DE)

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Description**FIELD**

[0001] The present invention relates to an energy distribution system, and more particularly to an energy distribution system architecture to control the distribution of energy to a system load.

BACKGROUND

[0002] Existing energy system architectures can include a logic-based controller implementing simple control logic to dispatch energy from an energy storage device, such as electrochemical batteries, to a load. The logic-based controller includes a predetermined set of thresholds and time stamps that define when a given energy storage device stores energy or is charged from available resources and when the storage device releases energy to a load. Examples of such logic-based controllers include load following controllers and cycle-charging controllers. With a load-following controller, the storage device is charged with energy provided by renewable resources when the energy is available and is discharged during a specified time of the day or when the load exceeds a specified threshold. With a cycle-charging controller, the storage device is charged when a dispatchable resource, such as a diesel generator, is running while also providing power to the load, and is discharged similarly to the load-following strategy. DE 10 2012 202465 A1 and WO 2012/145563 A1 teach a system and method for energy distribution.

[0003] DE 10 2012 202465 A1 discloses an energy control system configured to control the transmission of energy to an electrical load, comprising:

- a) a renewable energy resource and a dispatchable energy resource;
- b) a stored energy resource;
- c) a memory configured to store program instructions; and
- d) an energy system controller operably coupled to the renewable energy resource, to the dispatchable energy resource, to the stored energy resource, and to the memory, the energy system controller configured to execute the stored program instructions to
 - e) predict
 - e-i) an energy requirement of the load over a long time horizon, and
 - e-ii) predict energy to be generated by the renewable energy resource over the long time horizon,
 - e-iii) predict an energy potential of the dispatchable energy resource over the long time horizon.

[0004] While logic-based control systems provide for

the integration of energy storage devices into energy systems and can provide a certain amount of functionality, the logic-based control system can be deficient when attempting to recover the energy that has been stored and the economic benefits that can be provided by the energy storage system.

SUMMARY

[0005] In accordance with one embodiment of the present disclosure, there is provided an energy control system configured to control the transmission of energy to an electrical load. The energy control system includes a renewable energy resource, a stored energy resource, a memory configured to store program instructions, and an energy system controller operably coupled to the renewable energy resource, to the stored energy resource, and to the memory. The energy system controller is configured to execute the stored program instructions to predict an energy requirement of the load over a long time horizon, predict energy to be generated by the renewable energy resource over the long time horizon, predict energy capacity stored in the stored energy resource over the long time horizon, and generate optimally planned power profiles for the renewable energy resource and the stored energy resource. The controller also executes the stored program instructions to compare the predicted energy requirement, the predicted energy generation, and the predicted energy capacity to an actual energy requirement of the load, an actual energy generation by the renewable energy resource, and an actual energy capacity in the stored energy resource over a short time horizon, and controls the supply of energy to the electrical load based upon the comparison.

[0006] In another embodiment, there is provided a method for controlling the transmission of energy between an electrical load, a renewable energy resource, and a stored energy resource. The method includes the steps of predicting an energy requirement of the load over a long time horizon, predicting energy to be generated by the renewable energy resource over the long time horizon, predicting energy capacity stored in the stored energy resource over the long time horizon, generating optimally planned power profiles for each of the resources in the energy system on the long time horizon, comparing the predicted energy requirement, the predicted energy generation, and the predicted energy capacity to an actual energy requirement of the load, an actual energy generation by the renewable energy resource, and an actual energy capacity in the stored energy resource over a short time horizon, and controlling the supply of energy to the electrical load based upon the comparison.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007]

FIG. 1 is schematic block diagram of an energy system of the present invention.

FIG. 2 is a detailed schematic block diagram of the energy system of FIG. 1.

FIG. 3 is a schematic block diagram of an energy system controller of the present invention.

DESCRIPTION

[0008] For the purposes of promoting an understanding of the principles of the invention, reference will now be made to the embodiments illustrated in the drawings and described in the following written specification. It is understood that no limitation to the scope of the invention is thereby intended. It is further understood that the present invention includes any alterations and modifications to the illustrated embodiments and includes further applications of the principles of the invention as would normally occur to one of ordinary skill in the art to which this invention pertains.

[0009] FIG. 1 illustrates an energy system 100 that maximizes benefits of an energy system having one or more integrated energy resources. The energy system 100 includes an energy system controller 102 operatively coupled to an electrical load 104, through a communications line 103, which in one embodiment includes one or more electrical loads. The energy system controller 102 is also operatively coupled to one or more energy resources, including renewable energy resources 106 through a communications line 113, dispatchable energy resources 108 through a communications line 115, and stored energy resources 110 through a communications line 117. The electrical load 104, the renewable energy resources 106, the dispatchable energy resources 108, and the stored energy resources 110 are each operatively coupled to a power line 112 which provides for the transmission of energy from one or more of the energy resources to another energy resource and to the electrical load 104. A user interface, or human machine interface (HMI), and a data storage device 114 are also operatively coupled to the energy system controller 102 through a communications line 119. The communications lines 103, 113, 115, 117, and 119 are either hard-wired or wireless or a combination thereof.

[0010] The energy system controller 102 integrates a plurality of components, devices or subsystems that provide for the prediction of energy generation, the planning of energy delivery and storage, and the selective transmission or delivery of power from an energy generation device or an energy storage device to a load or an energy generation device. When the components, devices or subsystems are integrated into a single control system, the flow of energy is seamlessly delivered between the load, energy storage devices, dispatchable energy resources, and renewable resources to the benefit of the user. The controller 102 is operatively coupled to a controller 105 of the electrical load 104, a controller 107 of the renewable energy resources 106, a controller 109 of

the dispatchable energy resources 108, and a controller 111 of the stored energy resources 110. Each of the controllers, 105, 107, 109, and 111 in different embodiments, include processors and memories and receive and provide information in the form of signals to and from the controller 102. In addition, the controllers 105, 107, 109, and 111 in different embodiments include control hardware, including switching devices to provide for the generation and transmission of energy or the storage of energy within the energy system 100. The energy system 102 obtains status information from each of the resources 106, 108, and 110 as described later and also provides control signals to the controllers 105, 107, 109, and 111 for the generation and transmission or storage of energy in the system 100. The controller 102 is also operatively coupled to the controller 105 to receive status information of the load 104 indicative of the energy required by the load.

[0011] The controller 102 in different embodiments includes a computer, computer system, or programmable device, e.g., multi-user or single-user computers, desktop computers, portable computers and other computing devices. The controller 102 includes one or more individual controllers as described below and includes in different embodiments at least one processor coupled to a memory. The controller 102 includes in different embodiments one or more processors (e.g. microprocessors), and the memory in different embodiments includes random access memory (RAM) devices comprising the main memory storage of the controller 102, as well as any supplemental levels of memory, e.g., cache memories, non-volatile or backup memories (e.g. programmable or flash memories), read-only memories, etc. In addition, the memory in one embodiment includes a memory storage physically located elsewhere from the processing devices and includes any cache memory in a processing device, as well as any storage capacity used as a virtual memory, e.g., as stored on a mass storage device or another computer coupled to controller 102 via a network. The mass storage device in one embodiment includes a cache or other dataspace including databases.

[0012] The stored energy resources 110, in different embodiments, includes energy storage devices, such as electrochemical batteries such as those found in energy systems that supply electrical energy to residential loads, commercial loads or other types of loads and pumped hydro reserves. Utilization of the energy storage devices provides benefits in energy-savings by reducing the requirements for a distribution infrastructure and for integrating renewable energy resources into the electrical grid. Unlike conventional dispatchable resources which require a balance between the amount of energy generated and consumed by a grid at any instant of time, one or more storage devices enable the shifting of electrical energy consumption and energy generation from one period of time to another period of time. As a consequence, the energy generated by one or more renewable resources 106 which exceeds the amount of energy required by

a given load at a certain time to satisfy energy demand, in one embodiment, is stored in the energy storage resources 110. Renewable energy resources include wind turbines, solar panels, biomass plants, hydroelectric power plants, geothermal power installations, tidal power installations, and wave power installations. In addition low cost energy which is provided by the electrical grid at a low price during periods of low demand by the load 104 is also being stored. The stored energy is then being provided on demand when energy is required or when other forms of energy are more expensive. Dispatchable energy resources also include hydro-power, coal power, diesel generators, electrical grid connection, and gas power.

[0013] The use of energy storage resources 110 also provides a reliable supply of electrical power to maximize the benefits provided to owners, managers, or users of the energy system 100. Consequently, the described system and method for energy distribution including the energy system controller 102 realize the benefits of an energy storage system represented, for example, by a battery installation, while providing a reliable source of energy that satisfies load demand at substantially any and at all times. The energy system controller 102 is configured to plan for the optimal operation of many different types and configurations of energy systems.

[0014] As illustrated in FIG. 2, the control system architecture 100 maximizes the benefits of an energy system with integrated stored energy resources 110, here labeled as energy storage devices 110. One or more energy storage modules 120 are operatively connected to the power line 112 which couples the electrical load 104 to an energy grid 124. The module 120 represents different or similar types of energy storage devices. In addition, the renewable energy resources 106 and the dispatchable energy resources 108 are also coupled to the power line 112. To provide for the distribution of energy from the grid 124 and the resources 106, 108, and 110, energy system controller 102 includes three components or devices that individually and/or collectively solve the tasks of power prediction, power dispatch planning, and execution of power dispatch. A load and renewable predictors module 130 provides for a prediction of the power which is generated by the renewable resources 106 which in different embodiments is dependent upon a weather forecast received at an input 132 to the module 130. A dispatch planner module 134 provides for the planning of the generation and the release or discharge of energy to the load 104. A dispatch controller 136 dispatches or directs the flow of energy provided by the renewable resources 106, the dispatchable resources 108, and the energy stored in the storage devices 110 to the power line 112. Each of the load and renewable predictors module 130 and dispatch planner module 134 are embodied in one embodiment as modules including software resident in the controller 102 or which is one embodiment configured as individual device controllers. In addition, the dispatch controller 136 in one embodiment

is embodied as a module including software or as a device controller. While the modules 130, 134 and controller 136 in one embodiment are located at a single predetermined location, each of the modules 130, 134 and controller 136 in other embodiments are remotely located apart from each other if desired.

[0015] When the load and renewable predictors module 130, the dispatch planner module 134, and the dispatch controller 136 are integrated into the energy system controller 102, the modules 130, 134, and controller 136 in one embodiment direct the flow of energy and the amount of power available for the load 104 for/from the energy storage devices 110 and from the dispatchable resources 108, and the renewable resources 106 to maximize benefit of the user, which includes a cost benefit and an energy delivery benefit including the amount of electrical power and a time of its delivery.

[0016] Figure 2 illustrates the power line 112 which provides the electrical power connections to the renewable resources 106, the dispatchable resources 108, the energy storage devices 110, and to the electrical grid 124. The energy system controller 102 receives power measurements from the load, a status of renewable and dispatchable resources and storage devices, and receives historized operation and performance data from a data storage unit 140 coupled to the controller 102. In addition, the energy system controller 102 generates power control commands for the renewable resources 106, the dispatchable resources 108, and the storage devices 110.

[0017] The controller 102 includes a plurality of inputs to receive measurement and/or status signals. As described above, the input 132 provides weather information to the predictor module 130. The weather information is obtained from any number of providers including commercial weather prediction vendors and the NOAA National Weather Service. An input 150 to the module 130 provides a signal indicative of the present or current power requirement or status of the load 104, which is also provided to a comparator 152 to be described later. An input 154 to the predictor module 130 is received from the renewable resources 106 and provides status information of the amount of power currently being produced by the renewable resources 106. The status information provided by the input 154 is also provided to a comparator 156 to be described later.

[0018] Control commands are generated internally by the controller 102. The predictor module 130, for instance, generates signals over first and second predictor module outputs 160 and 162 which are received as inputs by the planner module 134. Similarly, in response to the signals received over the first and second predictor module 130 outputs 160, 162, the planner module 134 generates signals through planner module 134 outputs 164, 166, and 168. The signal at the output 164 is applied to the comparator 156 and combined with the signal at the output 154 generated by the renewable resource 106. The signal at the output 166 is applied to the comparator 152 and combined with the signal generated by the load

104 over the input 150. An output 170 of the comparator 156 is applied as an input to the dispatch controller 136. An output 172 of the comparator 152 is applied as an input to the dispatch controller 136. The dispatch controller 136 includes an output 180 coupled to the load 104, an output 182 coupled to the renewable resources 106, an output 184 coupled to the dispatchable resources 108, and an output 186 coupled to the storage devices 110.

[0019] In addition to the feedback and control commands described above, additional control information is transmitted over a data bus 190 coupled to the load 104, the renewable resources 106, the dispatchable resources 108, the storage devices 110, the data storage unit 140, the HMI 196, and the grid 124. The data bus 190, which includes other types of communication channels, transmits data that is used to communicate command signals and variables required for operation of the system 100. The data storage unit 140 stores data and transmits data upon demand from the controller 102. An output 192 from unit 196 is coupled to the controller 102 and an input 194 to the unit 196 is coupled to the controller 102 to receive command signals. A system operator or user accesses and/or manipulates data stored in the data storage unit 140 or data received from the controller 102 over the output 194. A user interface 196 (HMI) enables a user to access information about the state of the system 100, which in one embodiment is stored in the data storage unit 140 or received over the output 194.

[0020] FIG. 3 illustrates a detailed view of the energy system controller 102 and the configuration and types of signals being transmitted internally between the modules 130, 134, and controller 136 and externally to and from the load 104, the resources 106, 108, and 110, and to and from the HMI 196 and data storage unit 140. The load and renewables predictors module 130 generates a prediction of the requirements of the load, $\hat{P}_L(i)$ over the output 162 on a predetermined time horizon, T_H , and a prediction of the power to be generated or provided by the renewable resources $\hat{P}^R(i)$ which is transmitted over the output 160 using the same time horizon as used for the load signal at 162. These predictions are transmitted to the dispatch planner module 134 which processes the information and responsively generates a plurality of signals to control the operation of the energy system 100 on the time horizon T_H .

[0021] The dispatch planner 134 generates baseline power control commands (a vector of reference signals) $\bar{P}(i)$ for the dispatchable resources 108 on the output 168 for transmission to the dispatch controller 136. The dispatch planner module 134 also generates baseline power control commands (a vector of reference signals) for the renewable resources $\bar{P}^R(i)$ over the output 164 which along with the load prediction $\hat{P}_L(i)$, transmitted on the output 166, are compared respectively with the corresponding measurements of the power provided by the renewable resources, $P^R(k)$ at comparator 156, and the

load $P_L(k)$ at comparator 152, to generate error signals $e_R(k)$ and $e_L(k)$ respectively. The error signals and the reference signal for the dispatchable resources are then provided to the dispatch controller 136 that computes control commands for transmission to the renewable resources 106 ($c^R(k)$), dispatchable resources 108, ($c^D(k)$), storage devices 110, ($c^S(k)$), and the load 104, ($c^L(k)$). These control commands are provided to individual devices and implemented by the local controllers or a controller in communication with the device. The associated controller controls at least one switch at each of the resources 106, 108, and storage devices 110 to control the release of energy to the power line 112. The error signals indicate a difference between a predicted or planned power values and actual values of the load or power generation of the renewable resources, for instance.

[0022] In order to maximize the benefits provided by energy storage devices 110, operation of the energy storage devices 110 is planned on a sufficiently long time horizon, T_H , in the future so that the storage devices 110 in one embodiment is charged when energy in the system 100 is most readily available and/or least expensive. In different embodiments, the time horizon includes one or more hours, one or more days, or one or more weeks or other long time horizons. The stored energy is then provided on demand to the load 104 when the energy is most needed or when a predetermined level of savings is achieved if the load is being controlled to reduce load requirements. The dispatch planner module 134 in one embodiment performs an optimized planning of power profiles for the energy storage devices and other energy resources in the system by solving a numerical optimization problem using an optimization program or algorithm resident in firmware or software of the module 130 including memory associated with the module 130. Software resident at the user interface 114 in one embodiment is also used. In one embodiment, the long time horizon extends for one or more weeks, and the time periods used during the longer time horizon vary. For instance, during a first week, determinations of future power used and further power generation are made every hour. During a second week, determinations are made every six hours, and during a third week determinations are made every twelve hours. The determination of time periods in one embodiment is determined based on the accuracy of the weather predictions. When weather predictions are more accurate, for instance during a first week in the future, the determinations are made more often than during a second week in the future when weather predictions become less accurate.

[0023] The optimization problem is formulated with a cost function and takes into account the cost of energy, demand charges, battery efficiencies and life to depletion, maintenance and replacement costs for each component of the energy system, and other parameters that influence operating costs of the energy system 100 for a specified time horizon T_H . In addition to the cost function,

the optimization program takes into account all the constraints imposed on different components of the system such as power limits for various resources, available amounts of energy stored in different energy storage devices, and safety constraints. These algorithms and others described herein in one embodiment are embodied as program code or program instructions in software and/or firmware resident in one of the modules, the controller, in the user interface 114, or remote devices which are coupled to the system 100 through hardwired connections, connections to the internet, or other means of communication to software or firmware either wired or wireless.

[0024] To solve the described optimization problem, the dispatch planner module 134 receives a forecasted load profile over the specified time horizon T_H , profiles of power that are forecasted to be generated by the renewable resources over the same time horizon, and present states of energy system components such as the amount of fuel available for dispatchable resources and the amount of energy available from various storage devices. Information about the states of components of the energy system is provided to the dispatch planner module 134 by signal $S(k)$ over the output 192 from data storage unit 140 of Figure 2. Information indicative of the future load profile and power profiles from renewable resources 106 is provided to the dispatch planner module 134 by the load 104 and renewables predictors module 130.

[0025] Since at any given instant of time, the future load profiles of the load 104 and the future power profiles available from the renewable resources 106 are unknown, such profiles are forecasted. The load and renewables predictors module 130 includes a number of predictor algorithms that generate forecasts of the future load requirements of load 104 and the power anticipated to be available from renewable resources 106 on the prediction time horizon T_H . For example in an energy system 100 having one load connection, one photovoltaic (PV) installation, (typically including large arrays of PV cells), and one wind turbine, three predictors are provided for each one of these components. Each of these predictors is represented by a mathematical model of the considered component (e.g. load, PV installation, wind turbine) and models of physical processes that influence power consumption or generation of a given component. The predictor module 130 receives measurements of the power available from or provided to the component as well as other inputs that influence the power profile and generates a prediction of the power profile. These predictions are provided to the dispatch planner module 134 in the form of signals $\hat{P}_L(i)$ for the load 104 and $\hat{P}^R(i)$ for the renewable resources 106.

[0026] For example, the load predictor module 130 in one embodiment is implemented with a neural network model of the load 104 that is populated or trained with historical load profiles of the energy system 100 and is capable of generating a forecast of the load 104 which

occurs in the future on a timeline horizon of several hours or one or more days. In one example for instance, power requirements of a load are predicted based on power usage during a workweek as opposed to power usage during a weekend. Neural networks are known and are used in one embodiment.

[0027] The load predictor module 130 in one embodiment utilizes past measurements of the load power requirements as well as other variables such as current and future time variables, day of the week, time of the year, weather forecast on the specified time future horizon and other variables to generate the prediction $\hat{P}_L(i)$. A predictor algorithm for the PV installation in one embodiment is embodied by in program code providing a deterministic model that computes solar irradiance at a given geographical location for any time of the day and year which is adjusted by a weather forecast predicting cloud cover, humidity and other atmospheric parameters for time T_H in the future. The solar irradiance is considered in one embodiment as a part of the weather forecast. The power provided by the PV installation is determined than from the solar irradiance utilizing the mathematical model mapping irradiance into the power output. Similarly, the wind power predictor in one embodiment utilizes a mathematical model of the installed wind turbine along with the weather forecasts about temperature, humidity, wind speed and direction for the next time horizon T_H . Signal $P^R(k)$ provides information about the power generation by renewable resources at time instant k that is used by the predictors of the renewable power.

[0028] In one embodiment, a dispatch strategy computed by the dispatch planner module 134 relies on the prediction of load 104 and power available from the renewable resources 106. Due to prediction uncertainties and errors, modeling inaccuracies, and temporal variations in load profiles, and renewable profiles, a mismatch in one embodiment occurs between the predicted load and power profiles and the true load and power profiles. In addition to that mismatch, since both the predictors module 130 and dispatch planner module 134 need time to compute the predictions and the optimal dispatch strategy for the next time horizon, the predictors module 130 and dispatch planner module 134 of the energy system controller 102 in one embodiment operate at a sampling rate less than the speed required to compensate for an instantaneous variation of load demand and power supply. To compensate for the potentially faster variations of load demand and power supply from the renewable resources, the control system incorporates the dispatch controller 136. The dispatch controller 136 uses optimally planned profiles generated by the dispatch planner module 134 as reference inputs, and computes the errors, $e_R(k)$ and $e_L(k)$, between the predicted profiles and the measurements collected at a high sampling rate, and generates final command inputs to the energy system resources. In one embodiment, the predictors module 130 and the dispatch planner module 134 operate at a sampling rate of approximately between 15 minutes and

1 hour. This sampling rate is limited by the update rate of forecasts for the load 104 and renewable resources 106 and by the amount of time required to perform the optimization.

[0029] To compensate for the errors which accumulate due to prediction inaccuracies and temporal variations, the dispatch controller 136 compares reference inputs from the dispatch planner with the measurements received from the load $P_L(k)$ and renewable resources $P^R(k)$, computes the corresponding errors $e_L(k)$, $e_R(k)$ and augments reference commands from the dispatch planner module 134 with correction signals to generate power commands $c^D(k)$ to dispatchable resources 108, power commands $c^S(k)$ storage devices 110, throttling commands $c^R(k)$ to renewable resources 106 and, if load devices allow demand management, load regulation commands $c^L(k)$ to the load 104. In one embodiment command signals generated by the dispatch controller 136 are computed by augmenting the reference signals received from the dispatch planner module 134 with corrections that constitute fractions of the combined error,

$$e(k) = \sum e_R(k) - \sum e_L(k).$$

[0030] The throttling commands are generated in situations when the renewable resources 106 provide or are providing more power at a given sample time k than the amount of power than is capable of being absorbed by the load 104, storage devices 110 or the dispatchable resources 108. The throttling commands are transmitted to the renewable resources 106 to reduce the amount of energy being generated by the renewable resources. In the case of the PV arrays, in one embodiment the alignment of the arrays with respect to the sun are adjusted to misalign the arrays with respect to the path of sunlight, or in another embodiment the connection to the power line 112 is disconnected. In the case of wind turbines and in different embodiments, the blade angle is adjusted to limit the amount of rotation or the blades are disconnected from the gearbox or generator.

[0031] The sampling time for the dispatch controller 136 is denoted by k , while the sampling time for the predictors module 130 and the dispatch planner module 134 are denoted by i . This distinction is made to indicate that the sampling rate of the predictors module 130 and dispatch planner module 134 is slower than the faster sampling rate of the dispatch controller 136. In one embodiment, the sampling rate of the dispatch controller 136 is on the order of fractions of a minute to several seconds, milliseconds or other short time intervals. This sampling rate is limited by the sampling rates of the measurement devices acquiring instantaneous power of the load and the Renewable resources and the amount of time required to generate the control commands $c^R(k)$, $c^D(k)$, $c^S(k)$, $c^L(k)$.

[0032] The dispatchable energy resources 108 provide energy at times when the renewable energy resources

106, stored energy resources 110 are insufficient to meet the energy requirements of the load 104. In one embodiment, the dispatchable energy resource 108 provides a load matching function to provide an output to match the shape of the load demand. In another embodiment, peak matching is also provided to match the highest energy demand occurring during a certain time of day. Such time is predicted based on time of day, pattern of energy use, weather, and geographic location. The dispatchable energy resource 108 in other embodiments also cover lead-in times where some resources, such as coal powered plants, take a certain amount of time to ramp up to the desired output. Frequency regulation is also provided in some embodiments.

[0033] The control system architecture 100 facilitates robust operation in the presence of potential problems or failures in individual system components. For example, in one embodiment each one of the three modules 130, 134, and the controller 136 are implemented on an individual processor, server, programmable logic controller (PLC) or another computing device such that when one of these modules or controllers fail, one or more of the other modules or controller continue operation. In one embodiment, when each of the three components 130, 134, and 136 of the control system are implemented on the same device, as hardware, firmware or software, each is implemented as individual devices or programs, or program code, running independently and exchanging information between each other according to the described invention in order to provide the robust operation, such that power continues to be supplied if one of the components fails. In one embodiment, each of the components 130, 134, and 136 are independent of the other to provide for the failure of one or more of the other components.

[0034] If, for example, the predictors module 130 does not receive a weather update or fails to provide a new prediction at a certain time, the dispatch planner module 134 uses the predictions stored in an associated memory, or stored in the data storage 140, from the previous forecast, extrapolate it one step further according to a chosen rule, and generate a set of new reference signals for the dispatch controller 136. Such operation continues until the predictors module 130 restores its functionality and starts providing the forecast again. In this situation, the operation of the energy system 100 deviates from an optimal operation, but the controller 102 continues to reliably coordinate the transfer of power between the load 104 and the resources 106, 108, and 110. In another embodiment, if the dispatch planner module 134 fails, the dispatch controller 136 uses the planned profiles received from the dispatch planner module 134 during the previous time step and continue control of the system power until the planner module 134 operation is restored. In another embodiment, if the predictors module 130 or the dispatch planner module 134 fails for a sufficiently long period of time, longer than the prediction horizon of several hours or days, the dispatch controller 136 resorts

to a logic-based control of the power transmission until full functionality of the controller 102 is restored.

[0035] In terms of reliable operation of the energy system 100, a significant component of the control architecture is the dispatch controller 136. In general and in one embodiment, the control system controls power flow between the energy system resources as long as the dispatch controller 136 continues to be operational.

[0036] While the invention has been illustrated and described in detail in the drawings and foregoing description, the same should be considered as illustrative and not restrictive in character. While it is understood that only the certain embodiments have been presented, any and all changes, modifications and further applications that come within the scope of the invention are desired to be protected.

Claims

1. An energy control system (100) configured to control the transmission of energy to an electrical load (104), comprising:

a) a renewable energy resource (106) and a dispatchable energy resource (108);

b) a stored energy resource (110);

c) a memory configured to store program instructions; and

d) an energy system controller (102) operably coupled to the renewable energy resource (106), to the dispatchable energy resource (108), to the stored energy resource (110), and to the memory,

the energy system controller (102) comprising a predictor module (130), a dispatch planner module (134), and a dispatch module (136);

said predictor module (130) configured to receive a weather forecast indicative of the future occurrence of a weather pattern over a long time horizon and to

execute the stored program instructions to compare the predicted energy requirement, the predicted energy generation, and the weather forecast and to provide a first predictor indicative of a future energy requirement of the load (104) and a second predictor indicative of a future energy generation capability of the renewable energy resource (106);

said dispatch planner module (134) operatively coupled to the predictor module (130) and configured to

receive the first predictor and the second predictor and to

execute the stored program instructions to provide baseline power control commands for the dispatchable resource and for the renewable resource, and a load prediction command,

wherein the baseline power control commands and the load prediction command are provided as a result of solving a numerical optimization problem; and

said dispatch module (136) operatively coupled to the dispatch planner module (134) and configured to

execute the stored program instructions to provide a renewable resource control to the renewable energy resource (106) and a storage device control to the storage device resource both of which are generated at least in part from the baseline power control commands and the load prediction command,

wherein the dispatch module (136) controls the transmission of energy from the renewable energy resource (106) to the load (104) and to the storage device and controls the transmission of energy from the stored energy resource (110) to the load (104);

the energy system controller (102)

configured to execute the stored program instructions to

e) predict

e-i) an energy requirement of the load (104) over the long time horizon, and

e-ii) predict energy to be generated by the renewable energy resource (106) over the long time horizon,

e-iii) predict an energy potential of the dispatchable energy resource (108) over the long time horizon,

h) generate

h-i) a planned power profile for the renewable energy resource (106) over the long term horizon based on the predicted energy requirement e-1) and the predicted energy generation e-ii) and h-ii) a planned power profile for the stored energy resource (110) in the energy system (100) over the long time horizon based on the predicted energy requirement e-i) and the predicted energy generation e-ii),

i) compare the predicted energy requirement e-i), the predicted energy generation e-ii), and the predicted energy capacity g-i) to an actual energy requirement of the load (104), an actual energy generation by the renewable energy resource (106), and an actual energy capacity in the stored energy resource (110) over a short time horizon,

j) control the supply of energy to the electrical load (104) based upon the planned power profiles and the comparison;

wherein the energy system controller (102) is further configured, when executing the stored program instruction in said comparing feature i)

and said control feature j)), to execute stored program instructions to:

k) determine

k-i) an energy requirement error value by determining a difference between the predicted energy requirement e-i) and an actual energy requirement of the electrical load (104) over the short time horizon, and
k-ii) an energy generation error value by determining a difference between the predicted energy generation e-ii) and an actual energy generation of the renewable energy resource (106) over the short time horizon; and

l) control

l-i) a throttling of the renewable energy resource (106) based on the planned power profile h-i) for the renewable energy resource (106), the energy requirement error value k-i) and the energy generation error value k-ii), and
l-ii) a charging and discharging of the stored energy resource (110) based in the planned power profile h-ii) for the stored energy resource (110), the energy requirement error value k-i) and the energy generation error value k-ii).
wherein the long time horizon is on the order of at least one of a day and a week, and wherein the short time horizon is on the order of at least one of a second, a minute and an hour.

2. The energy control system (100) of claim 1, wherein the renewable energy resource (106) comprises at least one of a photovoltaic installation, a wind turbine, a biomass plant, a hydroelectric power plant, a geothermal power installation, a tidal power installation, and a wave power installation.
3. The energy control system (100) of claim 2, wherein the weather forecast indicative of the future occurrence of a weather pattern includes at least one of solar irradiance, cloud cover, humidity, and wind speed and direction.
4. The energy control system (100) of claim 1, wherein the renewable energy resource (106) comprises a photovoltaic installation.

Patentansprüche

1. Energiesteuerungssystem (100), das konfiguriert ist, die Energieübertragung zu einer elektrischen

Last (104) zu steuern, wobei es Folgendes umfasst:

a) eine Quelle (106) für erneuerbare Energie und eine Quelle (108) für abrufbare Energie;
b) eine Quelle (110) für gespeicherte Energie;
c) einen Datenspeicher, der konfiguriert ist, Programmanweisungen zu speichern; und
d) eine Energiesystemsteuereinheit (102), die mit der Quelle (106) für erneuerbare Energie, der Quelle (108) für abrufbare Energie, der Quelle (110) für gespeicherte Energie und dem Datenspeicher betriebstechnisch gekoppelt ist, wobei die Energiesystemsteuereinheit (102) ein Vorhersagemodul (130), ein Abrufplanungsmodul (134) und ein Abrufmodul (136) umfasst; wobei das Vorhersagemodul (130) konfiguriert ist zum

Empfangen einer Wettervorhersage, die das zukünftige Auftreten eines Wettermusters über einen langen Zeithorizont angibt, und zum

Ausführen der gespeicherten Programmanweisungen, um den vorhergesagten Energiebedarf, die vorhergesagte Energieerzeugung und die Wettervorhersage zu vergleichen und um eine erste Vorhersagefunktion, die einen zukünftige Energiebedarf der Last (104) angibt, und eine zweite Vorhersagefunktion, die eine zukünftige Energieerzeugungskapazität der Quelle (106) für erneuerbare Energie angibt, bereitzustellen;

wobei das Abrufplanungsmodul (134) mit dem Vorhersagemodul (130) betriebstechnisch gekoppelt ist und konfiguriert ist zum

Empfangen der ersten Vorhersagefunktion und der zweiten Vorhersagefunktion, und zum

Ausführen der gespeicherten Programmanweisungen, um Grundleistungssteuerbefehle für die abrufbare Quelle und für die erneuerbare Quelle und einen Lastvorhersagebefehl bereitzustellen, wobei die Grundleistungssteuerbefehle und der Lastvorhersagebefehl als ein Ergebnis des Lösen eines numerischen Optimierungsproblems bereitgestellt werden; und

wobei das Abrufmodul (136) mit dem Abrufplanungsmodul (134) betriebstechnisch gekoppelt ist und konfiguriert ist zum

Ausführen der gespeicherten Programmanweisungen, um der Quelle (106) für er-

erneuerbare Energie eine Steuerung der erneuerbaren Quelle und der Speichervorrichtungsquelle eine Steuerung für die Speichervorrichtung bereitzustellen, die beide zumindest teilweise aus den Grundleistungssteuerbefehlen und dem Lastvorhersagebefehl erzeugt werden, wobei das Abrufmodul (136) die Energieübertragung von der Quelle (106) für erneuerbare Energie an die Last (104) und an die Speichervorrichtung steuert und die Energieübertragung von der Quelle (110) für gespeicherte Energie an die Last (104) steuert;

wobei die Energiesystemsteuereinheit (102) konfiguriert ist, die gespeicherten Programmanweisungen auszuführen zum

e) Vorhersagen

e-i) eines Energiebedarfs der Last (104) über den langen Zeithorizont, und

e-ii) Vorhersagen der Energie, die durch die Quelle (106) für erneuerbare Energie über den langen Zeithorizont erzeugt werden muss,

e-iii) Vorhersagen eines Energiepotentials der Quelle (108) für abrufbare Energie über den langen Zeithorizont,

h) Erzeugen

h-i) eines geplanten Leistungsprofils für die Quelle (106) für erneuerbare Energie über den langen Zeithorizont auf der Grundlage des vorhergesagten Energiebedarfs e-i) und der vorhergesagten Energieerzeugung e-ii) und h-ii) eines geplanten Leistungsprofils für die Quelle (110) für gespeicherte Energie im Energiesystem (100) über den langen Zeithorizont auf der Grundlage des vorhergesagten Energiebedarfs e-i) und der vorhergesagten Energieerzeugung e-ii),

i) Vergleichen des vorhergesagten Energiebedarfs e-i), der vorhergesagten Energieerzeugung e-ii) und der vorhergesagten Energiekapazität g-i) mit einem tatsächlichen Energiebedarf der Last (104), einer tatsächlichen Energieerzeugung durch die Quelle (106) für erneuerbare Energie und einer tatsächlichen Energiekapazität in der Quelle (110) für gespeicherte Energie über einen kurzen Zeithorizont,

j) Steuern der Energiezufuhr an die elektrische Last (104) auf der Grundlage der geplanten Leistungsprofile und des Vergleichs;

wobei die Energiesystemsteuereinheit (102) ferner konfiguriert ist, dann, wenn die gespeicherten Programmanweisungen im Vergleichsmerkmal i) und im Steuermerkmal j) ausgeführt

werden, gespeicherte Programmanweisungen auszuführen zum:

k) Bestimmen

k-i) eines Energiebedarfsfehlerwertes durch Bestimmen einer Differenz zwischen dem vorhergesagten Energiebedarf e-i) und einem tatsächlichen Energiebedarf der elektrischen Last (104) über den kurzen Zeithorizont, und

k-ii) eines Energieerzeugungsfehlerwertes durch Bestimmen einer Differenz zwischen der vorhergesagten Energieerzeugung e-ii) und einer tatsächlichen Energieerzeugung der Quelle (106) für erneuerbare Energie über den kurzen Zeithorizont; und

l) Steuern

l-i) einer Drosselung der Quelle (106) für erneuerbare Energie auf der Grundlage des geplanten Leistungsprofils h-i) für die Quelle (106) für erneuerbare Energie, des Energiebedarfsfehlerwertes k-i) und des Energieerzeugungsfehlerwertes k-ii), und

l-ii) eines Aufladens und Entladens der Quelle (110) für gespeicherte Energie auf der Grundlage des geplanten Leistungsprofils h-ii) für die Quelle (110) für gespeicherte Energie, des Energiebedarfsfehlerwertes k-i) und des Energieerzeugungsfehlerwertes k-ii),

wobei der lange Zeithorizont in der Größenordnung eines Tages und/oder einer Woche liegt, und

wobei der kurze Zeithorizont in der Größenordnung einer Sekunde und/oder einer Minute und/oder einer Stunde liegt.

2. Energiesteuerungssystem (100) nach Anspruch 1, wobei die Quelle (106) für erneuerbare Energie eine Photovoltaikanlage und/oder ein Windkraftwerk und/oder ein Biomassekraftwerk und/oder ein Wasserkraftwerk und/oder ein Erdwärmekraftwerk und/oder ein Gezeitenkraftwerk und/oder ein Wellenkraftwerk umfasst.
3. Energiesteuerungssystem (100) nach Anspruch 2, wobei die Wettervorhersage, die das zukünftige Auftreten eines Wettermusters angibt, Sonneneinstrahlung und/oder Wolkendecke und/oder Feuchtigkeit und/oder Windgeschwindigkeit und -richtung enthält.
4. Energiesteuerungssystem (100) nach Anspruch 1, wobei die Quelle (106) für erneuerbare Energie eine Photovoltaikanlage umfasst.

Revendications

1. Système de contrôle d'énergie (100) configuré pour contrôler la transmission d'énergie à une charge électrique (104), le système comprenant :
 - a) une ressource d'énergie renouvelable (106) et une ressource d'énergie distribuable (108) ;
 - b) une ressource d'énergie stockée (110) ;
 - c) une mémoire configurée pour stocker des instructions de programme ; et
 - d) un contrôleur de système d'énergie (102) couplé de manière fonctionnelle à la ressource d'énergie renouvelable (106), à la ressource d'énergie distribuable (108), à la ressource d'énergie stockée (110) et à la mémoire, le contrôleur de système d'énergie (102) comprenant un module prédictif (130), un module planificateur de distribution (134) et un module de distribution (136) ;
 ledit module prédictif (130) étant configuré pour :
 - recevoir une prévision météorologique indiquant la survenue future d'un modèle météorologique à long terme, et
 - exécuter les instructions de programme stockées pour comparer l'exigence prédite d'énergie, la génération prédite d'énergie et la prévision météorologique et pour fournir une première prédiction indiquant une exigence future d'énergie de la charge (104) et une seconde prédiction indiquant une capacité de génération future d'énergie de la ressource d'énergie renouvelable (106) ;
 - ledit module planificateur de distribution (134) étant couplé de manière fonctionnelle au module prédictif (130) et étant configuré pour :
 - recevoir la première prédiction et la seconde prédiction, et
 - exécuter les instructions de programme stockées pour fournir des commandes de contrôle de puissance de référence pour la ressource distribuable et pour la ressource renouvelable et une commande de prédiction de charge, les commandes de contrôle de puissance de référence et la commande de prédiction de charge étant fournies à la suite de la résolution d'un problème d'optimisation numérique ; et
 - ledit module de distribution (136) étant couplé de manière fonctionnelle au module planificateur de distribution (134) et étant configuré pour :

exécuter les instructions de programme stockées pour fournir un contrôle de ressource renouvelable à la ressource d'énergie renouvelable (106) et un contrôle de dispositif de stockage à la ressource de dispositif de stockage, qui sont générés l'un et l'autre, au moins en partie, à partir des commandes de contrôle de puissance de référence et de la commande de prédiction de charge, le module de distribution (136) contrôlant la transmission d'énergie de la ressource d'énergie renouvelable (106) à la charge (104) et au dispositif de stockage et contrôlant la transmission d'énergie de la ressource d'énergie stockée (110) à la charge (104) ; le contrôleur de système d'énergie (102) étant configuré pour exécuter les instructions de programme stockées pour :

e) prédire

- e-i) une exigence d'énergie de la charge (104) à long terme, et
- e-ii) une énergie à générer par la ressource d'énergie renouvelable (106) à long terme,
- e-iii) une énergie potentielle de la ressource d'énergie distribuable (108) à long terme,

h) générer

- h-i) un profil planifié de puissance pour la ressource d'énergie renouvelable (106) à long terme sur la base de l'exigence prédite d'énergie e-1) et de la génération prédite d'énergie e-ii), et
- h-ii) un profil planifié de puissance pour la ressource d'énergie stockée (110) dans le système d'énergie (100) à long terme sur la base de l'exigence prédite d'énergie e-i) et de la génération prédite d'énergie e-ii),

- i) comparer l'exigence prédite d'énergie e-i), la génération prédite d'énergie e-ii) et la capacité prédite d'énergie g-i) à une exigence réelle d'énergie de la charge (104), à une génération réelle d'énergie par la ressource d'énergie renouvelable (106) et à une capacité réelle d'énergie dans la ressource d'énergie stockée (110) à court terme,
- j) contrôler l'alimentation en énergie de la charge électrique (104) sur la base des profils planifiés de puissance et de la comparaison ;

le contrôleur de système d'énergie (102) étant en outre configuré, lors de l'exécution des instructions de programme stockées dans le cadre de ladite opération de comparaison i) et de ladite opération de contrôle j), pour exécuter des instructions de programme stockées pour :

- k-i) une valeur d'erreur d'exigence d'énergie en déterminant une différence entre l'exigence prédite d'énergie e-i) et une exigence réelle d'énergie de la charge électrique (104) à court terme, et
- k-ii) une valeur d'erreur de génération d'énergie en déterminant une différence entre la génération prédite d'énergie e-ii) et une génération réelle d'énergie de la ressource d'énergie renouvelable (106) à court terme ; et

l) contrôler

- l-i) une limitation de la ressource d'énergie renouvelable (106) sur la base du profil planifié de puissance h-i) pour la ressource d'énergie renouvelable (106), de la valeur d'erreur d'exigence d'énergie k-i) et de la valeur d'erreur de génération d'énergie k-ii), et
- l-ii) une recharge et une décharge de la ressource d'énergie stockée (110) sur la base du profil planifié de puissance h-ii) pour la ressource d'énergie stockée (110), de la valeur d'erreur d'exigence d'énergie k-i) et de la valeur d'erreur de génération d'énergie k-ii),

le long terme étant de l'ordre d'au moins une durée parmi un jour et une semaine, et le court terme étant de l'ordre d'au moins une durée parmi une seconde, une minute et une heure.

4. Système de contrôle d'énergie (100) selon la revendication 1, dans lequel la ressource d'énergie renouvelable (106) comprend une installation photovoltaïque.

2. Système de contrôle d'énergie (100) selon la revendication 1, dans lequel la ressource d'énergie renouvelable (106) comprend au moins une installation parmi une installation photovoltaïque, une turbine éolienne, une centrale biomasse, une centrale hydroélectrique, une installation d'énergie géothermique, une installation marémotrice et une installation houlomotrice.
3. Système de contrôle d'énergie (100) selon la revendication 2, dans lequel la prévision météorologique indiquant la survenue future d'un modèle météorologique inclut au moins un paramètre parmi une irradiation solaire, une couverture nuageuse, une humidité et une vitesse et une direction du vent.

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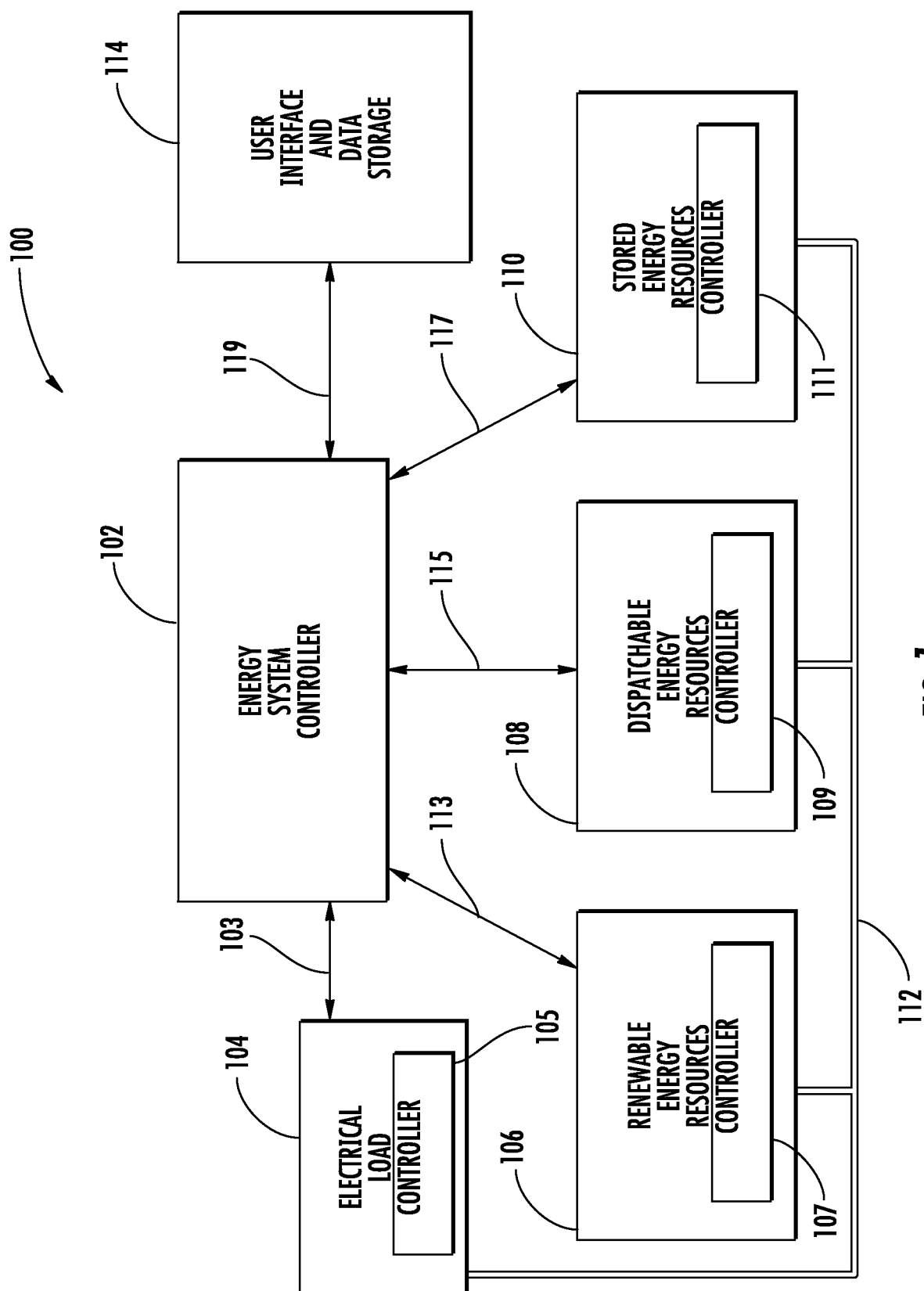


FIG. 1

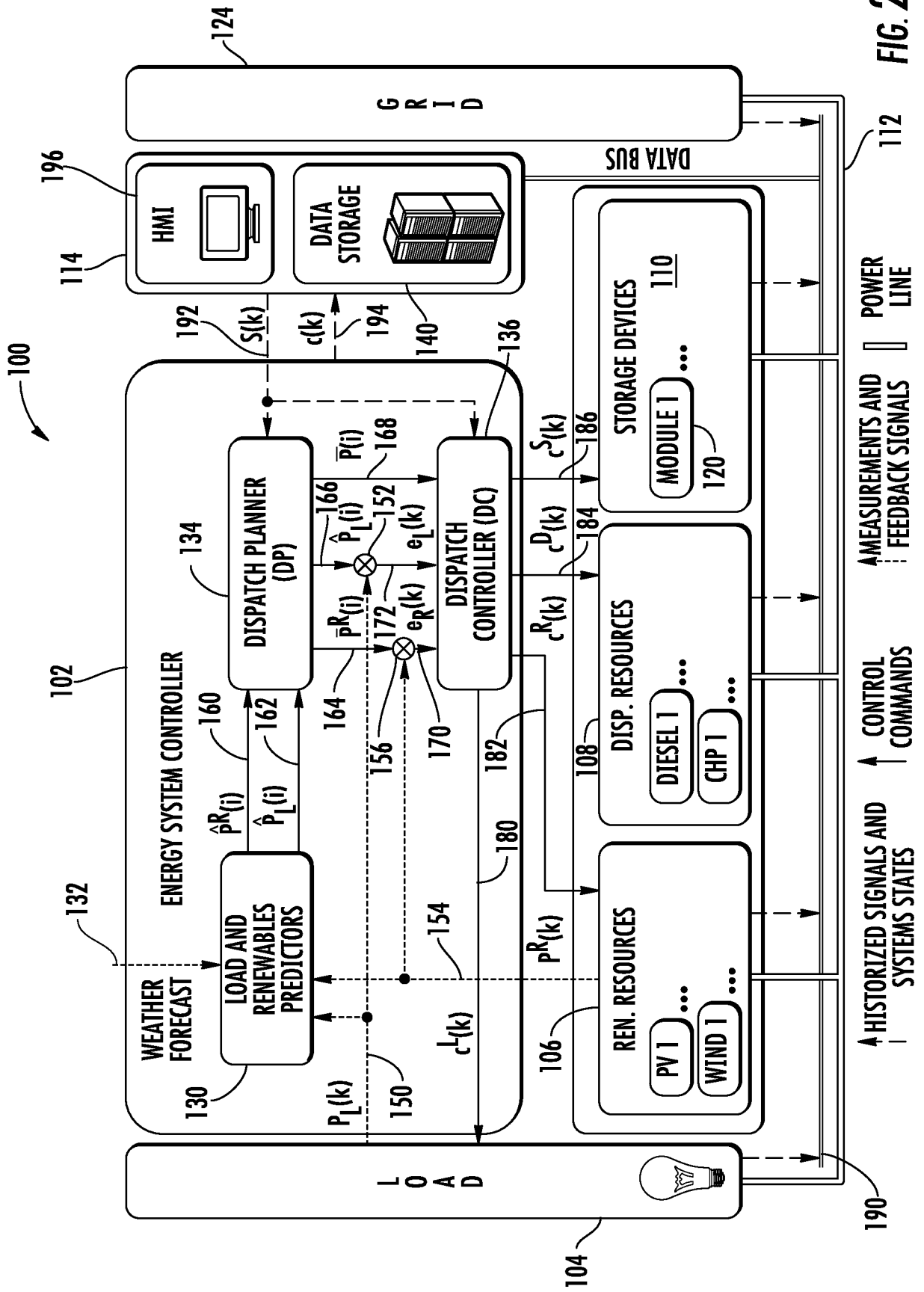


FIG. 2

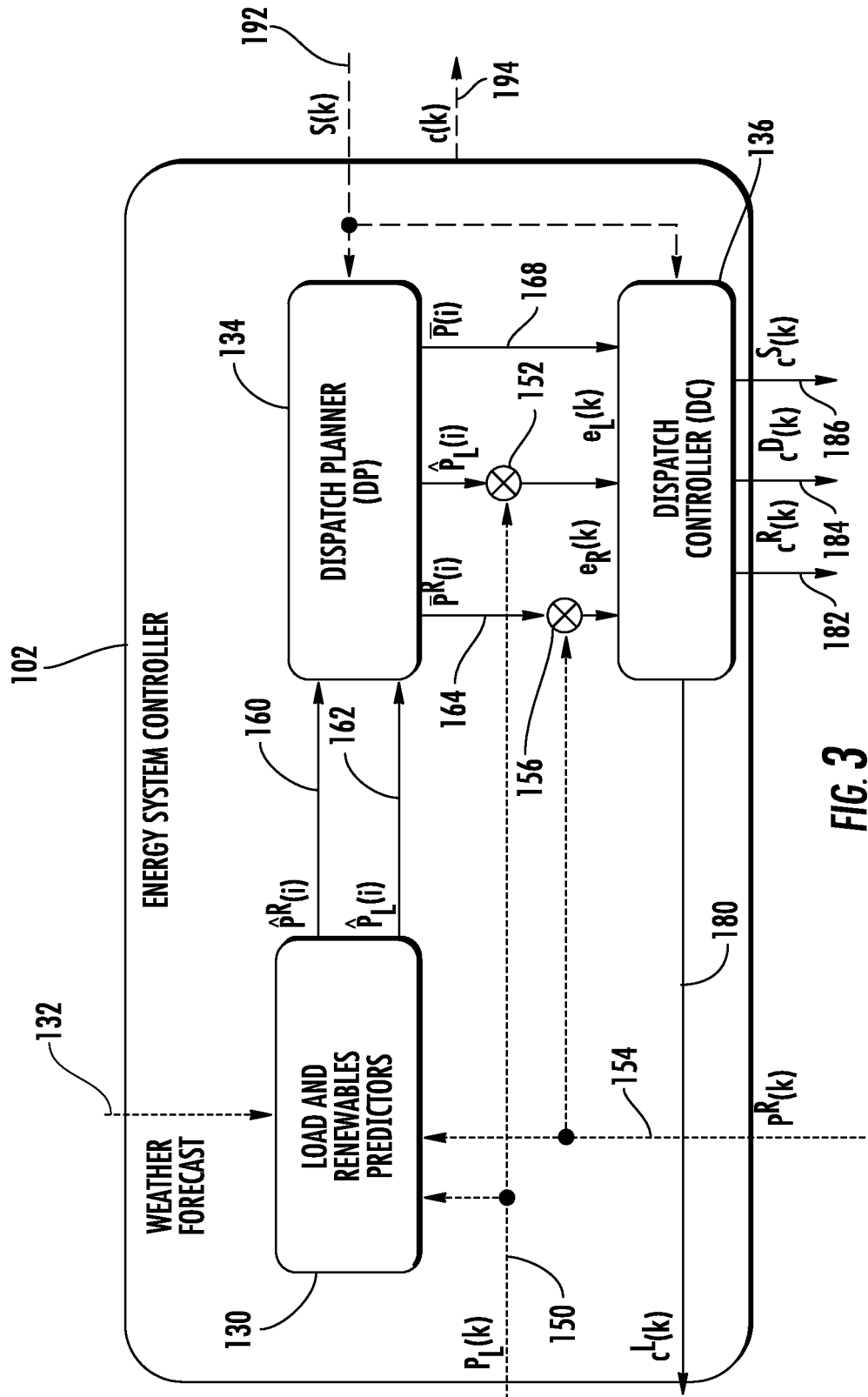


FIG. 3

REFERENCES CITED IN THE DESCRIPTION

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